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Preschooler's Self-Regulation Following Outdoor Play and Unstructured Physical Activity

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Preschooler's Self-Regulation Following Outdoor Play and Unstructured Physical Activity

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Abstract

Preschooler's Self-Regulation Following Outdoor Play and Unstructured Physical Activity

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Educators and policymakers increasingly seek to support the development of young children's self-regulation. One approach that has shown promise in school-aged children but has been rarely tested in the preschool years is providing children opportunities to engage in physical activity. This study examined whether preschoolers' task-based and classroom-based self-regulation depended on the timing of their outdoor play and the amount of physical activity in which children engaged during outdoor play. This study found within-child differences in children's observed classroom-based self-regulation following outdoor play, with more pronounced differences for younger children. The amount of physical activity in which children engaged during outdoor play predicted their subsequent task-based self-regulation.

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Introduction

Children's self-regulation -- in other words, their ability to manage their attention and behavior in goal-directed ways (Bailey & Jones, 2019) -- is a critical component of school readiness. Self-regulation enables children to enact appropriate behavior, to attend to lessons and activities, and to get along with others (Ursache et al., 2012). Early childhood is a period of rapid growth in self-regulation (Best & Miller, 2010; Zelazo et al., 2016), making it a critical period in which to support the development of these skills. They are important for children's academic success, as they predict young children's language and literacy skills (Moffett & Morrison, 2019; Weiland et al., 2014) as well as their math and numeracy skills (McKinnon & Blair, 2019; Wolf & McCoy, 2019). The importance of self-regulation for school readiness and later achievement has made it a key target of early intervention to address school readiness and achievement gaps (Blair & Raver, 2015).

One way to promote young children's self-regulation in the classroom may be to allow children to engage in physical activity outdoors, an approach that has been shown to be effective with children of elementary school age (Donnelly et al., 2016). This strategy aligns with conventional wisdom that young children can more easily pay attention and sit still after outdoor play. Despite this intuitive hypothesis, few studies have tested this premise in early childhood. Most studies of children aged 0-6 have examined longitudinal links between physical activity and children's including self-regulation rather than the immediate impact of outdoor play and physical activity (Carson et al., 2016; Zeng et al., 2017).

If outdoor play and physical activity promote subsequent self-regulation, adjusting the timing of young children's outdoor play and physical activity to support children's self-regulation in the classroom is something that many early childhood centers could implement, as outdoor play is already a standard feature of these settings. A handful of studies have examined the immediate impact of physical activity on children's self-regulation in early childhood (Stein et al., 2017; Tandon et al., 2018; Webster et al., 2015). We review these in a later section but first describe how we defined self-regulation in this study, as the literature on the topic of self-regulation is complicated by the varying terms and approaches that researchers use to study it (Jones et al., 2016).

DEFINING SELF-REGULATION

Researchers from various disciplines have studied self-regulation with different nomenclatures (Nigg, 2017). Cognitive psychologists studying executive function emphasize aspects of cognitive flexibility, working memory, and inhibitory control (Diamond, 2013). Scholars of emotion regulation, on the other hand, focus on the temperamental aspects of emotional, attentional, and impulse control (Eisenberg, Smith, & Spinrad, 2004). Both research traditions, however, emphasize the ability to intentionally manage thoughts and behaviors (Gagne, 2017; Liew, 2012). Reflecting this overlap, Bailey and Jones (2019) proposed an integrated model in which a set of self-regulatory skills in early childhood (i.e., inhibitory control, attentional control, cognitive flexibility, and working memory) can be applied in different developmental domains.

Self-regulation can be applied across many situations, and researcher also distinguish between self-regulation that is displayed in an affectively or motivationally neutral situation ("cool" self-regulation) versus the enactment of the same skills in situations in which an internal motivation is salient ("hot" self-regulation) (Zelazo & Carlson, 2012). The latter are relevant to everyday situations when young children must intentionally control their attention and behavior, such as during regular classroom activities. Children's "cool" self-regulation is typically assessed through structured one-on-one activities tasks.

Inhibitory control

Inhibitory control refers to the ability to override an automatic response and enact another (McClelland et al., 2018). "Cool" or task-based inhibitory control is often measured using a Stroop-like paradigm in which children must suppress an automatic response to a stimulus or prompt and enact a subdominant response, often by doing the opposite of what an assessor instructs them to do (Carlson, 2005; Ponitz et al., 2009).

Children display “hot” inhibitory control during classroom activities when they follow classroom norms or routines that require inhibiting automatic or desired responses, such as resisting the urge to call out an answer and instead raise their hand before speaking (McCoy, 2019). Inhibitory control in kindergarten shows links to math and reading achievement in first grade (McKinnon & Blair, 2019) and in third grade (Nguyen & Duncan, 2019).

Shifting

Shifting, also known as cognitive flexibility, refers to the ability to transfer attention fluidly between tasks or direct behavior according to changing sets of rules (Blair, 2016). “Cool” or task-based shifting is commonly measured using the Dimensional Change Card Sort task, in which children must sort a set of cards first by color, and then by shape (Zelazo, 2006). “Hot” or classroom-based shifting might occur when children adapt to suggestions from peers for incorporating new rules into joint play (McCoy et al., 2017). Shifting predicts math and reading achievement in first grade (McKinnon & Blair, 2019; Willoughby et al., 2019) as well as academic achievement in third grade (Nguyen & Duncan, 2019).

Working memory

Working memory refers to the ability to actively hold and manipulate information in one’s mind (Diamond, 2013; Miyake et al., 2000). Researchers often assess this in children using the Numbers Reversed task, in which children must recall a string of numbers in backward order (e.g., Willoughby et al., 2019). Working memory is most easily observed in “cool,” task-based paradigms, but one could observe children engage working memory in the classroom setting (“hot” working memory) as children remember and enact a series of steps in the correct order (McCoy et al., 2017). Working memory shows the most robust relationships with later achievement, extending through elementary school (Nguyen & Duncan, 2019) and into adolescence (Ahmed et al., 2019). Deficits in working memory and cognitive flexibility, on the other hand, predict an increased risk of continued academic difficulty (Morgan et al., 2019).

Attentional control

Attentional control refers to the ability to sustain focus, ignore distractions, and shift attention (Bailey & Jones, 2019). Many of the cognitive tasks assessing executive function do not directly target attentional control but do require it for successful completion. "Hot" or classroom-based attention control includes following along with classroom activities, showing evidence of listening by responding to questions or verbal prompts, and ignoring distractions from peers or objects in the environment (Jones, Bailey, et al., 2016). A study using several national, longitudinal datasets showed that attentional control was unique among non-academic skills in predicting children's achievement in school (Duncan et al., 2007).

APPROACHES TO MEASURING SELF-REGULATION

Self-regulation is an internal process that cannot be observed directly, so researchers who study it must rely on observable behavioral responses that indicate the use of specific skills (McCoy, 2019). We incorporate three approaches that do so: one-on-one assessments indicating children's "cool," task-based self-regulation, observations of children's behavior in their classrooms to indicate their "hot" or classroom-based self-regulation, and adult reports of their overall, temperamental levels of self-regulation, which may reflect both "hot" and "cool" aspects of self-regulation.

To examine "cool" or task-based self-regulation, researchers have developed structured tasks that incorporate demands on children's inhibitory control, cognitive flexibility, and working memory, typically completing them via direct assessments in laboratory settings (e.g., Zelazo, 2006). Direct assessments offer standardized assessment and scoring, but skills demonstrated in a lab or in affectively neutral situations may not translate to a classroom context with many other competing demands on attention and behavior (Jones et al., 2016; McClelland & Cameron, 2012). In fact, Obradović and colleagues (2018) found that a contextual, group-based assessment of executive function was more predictive of students' later achievement than the same task administered one-on-one, an ostensibly "cooler" version of the same task.

An emerging approach to assessing children's self-regulation is to conduct direct observations of children during their regular classroom activities (McCoy, 2019). Observations in the classroom setting capture children's ability to use self-regulatory skills amid competing distractions and motivation (McCoy et al., 2017), making them a good way to assess children's "hot" or classroom-based self-regulation. Observational approaches also allow examination of how children's self-regulation might vary within-child based on situational factors (Koepp et al., 2019). Few studies have examined this kind of variation explicitly, even as a rich body of developmental theory considers contextual influences integral to children's behavioral development (e.g., Sameroff, 2009).

In addition to direct assessments and observations, researchers have also used adult ratings to quantify children's self-regulation skills (McCoy, 2019; Putnam & Rothbart, 2006). In contrast to direct assessments, teacher and parent reports of children's skills provide information about these skills in context and across situations. These reports, however, are more global in what that they assess and are not designed to describe within-person differences in self-regulation across classroom situations or study conditions (Ahmed, 2019; McCoy, 2019). In this study, we rely on teacher reports of children's temperamental levels of self-regulation to examine moderation of the impact of outdoor play and physical activity.

THEORETICAL FRAMEWORK

Developmental theories provide ways to describe how children's immediate contexts might influence their self-regulation. The bioecological model (Bronfenbrenner & Morris, 2006) maintains that factors within children's micro-contexts, in this case their classrooms and schools, have direct influences on children's behavior. Sameroff's (2009) transactional theory of development considers how the transactions between children and their environments shape their abilities to regulate their behavior. Both of these perspectives imply that children's self-regulation will be enhanced or taxed by the everyday situations around them, potentially predicting within-child differences in behavior according to external factors.

An approach investigating within-child differences would seem to contradict a substantial literature providing evidence that self-regulation is part of one's temperament—in other words, that self-regulation is a stable, person-level construct (Eisenberg et al., 2004). Underlying the stability view is a consensus that self-regulation has a basis in neural systems, acknowledged by temperament researchers (Morris et al., 2017; Rothbart, 2007) and those from cognitive (Zelazo & Carlson, 2012) and neuro-developmental perspectives (Blair, 2016; Diamond, 2013). Although attentional control, inhibitory control, cognitive flexibility, and working memory can be improved (Diamond & Ling, 2016; Jones et al., 2011; Raver et al., 2011), most work assumes these skills to be relatively stable within-person.

To integrate these perspectives, we propose a model of continuous transactions, in which an individual's self-regulation is challenged or supported by situational factors, resulting in observable differences in behavior. This is similar to the "dynamic microprocesses" of a transactional system described by Olson and Lunkenheimer (2009). In this model, situational factors lead to within-child variation in regulation-related behaviors. Such interactions may serve as building blocks for the development of self-regulation. Ursache et al. (2012) described an iterative model of self-regulation in which reactions to external stimuli prompt the intentional activation, inhibition, or modulation of behaviors to manage them. We maintain that it is the continual interaction between these "top-down" and "bottom-up" processes that leads to behavioral differences in the moment and provides opportunities to enact and practice skills for self-regulation.

Exploratory empirical work has documented that children's observed self-regulation varies across classroom activities, as this model would predict (Koepp et al., 2019). For example, children showed better attention and inhibitory control during structured transitions compared to other classroom activities, and poorer attention during reading exercises involving the whole class. We extend this line of inquiry in the present study to examine how children's behavior may vary according to the timing of children's outdoor play and physical activity. In particular, children's self-regulation may differ following outdoor play compared to indoor classroom activities because these incorporate different demands on children's behavior. Indeed, children's behaviors in both indoor and outdoor contexts are based both on teacher's expectations and guidance as well as toys and opportunities for play across each.

The bioecological model (Bronfenbrenner & Morris, 2006) describes how children's behavior is influenced by their immediate contexts, including the structured opportunities and activities that adult caregivers provide to children. Indoor play in many early childhood settings consists of primarily sedentary activities devoted to creative exploration and fine motor development (e.g. drawing, crafts, or puzzles) or centers with seated activities to build pre-academic skills (e.g. literacy center). Some centers provide opportunities for limited movement within a restricted range of activity (e.g. block building or dramatic play). Outdoor spaces, on the other hand, often have balls and other objects for throwing, and gross motor toys such as tricycles or scooters, as well as slides and sandboxes. These toys and structures provide opportunities for and prompt different kinds of play from children. The indoor and outdoor settings are deliberately set up for children to engage in different types of play and provide cues for appropriate behavior.

Teachers also reinforce different behavioral expectations during outdoor versus indoor play. Though it may be perfectly acceptable, even encouraged, for children to run, hop, or jump while outside, such movements inside the classroom would quickly catch the attention of a teacher and prompt redirection. Chasing other children or playing catch are other examples of outdoor play that would be discouraged inside the classroom. That is not to say that outdoor play is without expectations for appropriate behavior. Indeed, rules and norms such as sharing toys or not hitting other children still apply. In general, however, a much wider range of physical activity, volume, and movement is expected and tolerated outdoors.

Because indoor activities place additional constraints on the behavior expected of children compared to outdoor play, these activities may draw on children's resources for self-regulation and potentially deplete them. Outdoor activities, on the other hand, could enhance these same resources by providing both a break from more restrictive expectations of behavior as well as opportunities for physical activity. Thus, children's immediate contexts, namely the indoor and outdoor environments of the school, as well as teachers' behavioral expectations for those spaces place different demands on children's self-regulation. The different demands from these environments could ultimately deplete or enhance children's abilities to manage their attention and behavior while at school. We view these transactions as a dynamic microprocess (Olson & Lunkenheimer, 2009), with children reacting to the different opportunities for play and expectations for behaviors across the indoor and outdoor settings.

The transactional theory of development (Sameroff, 2009) also provides a lens to consider how children may respond differently to the same environments. Children who are temperamentally less-regulated may over-engage in physical activity or engage in more dysregulated behavior during outdoor play. These children may be less able to down-regulate their activity or arousal upon returning to activities inside the classroom. As a result, they might show lower levels of self-regulation following outdoor play. On the other hand, these children might benefit the most from an opportunity to expend restless energy through physical activity outside and might show higher levels of self-regulation following outdoor play. We present both of these possibilities as exploratory hypotheses.

SELF-REGULATION AND PHYSICAL ACTIVITY

A handful of intervention studies have tested the link between preschoolers' activity levels and their self-regulation. Intervention studies are instructive because they experimentally manipulate children's physical activity, generating confidence that changes in children's self-regulation can be attributed to differences in the activities that precede them. These studies frequently use a within-person design, comparing children's self-regulation following a sedentary condition to their self-regulation following a physically active condition.

Studies employing these designs with preschoolers have found limited evidence that physical activity promotes children's task-based self-regulation . One such study found no within-child differences in task-based cognitive flexibility and inhibitory control for kindergarteners following a twenty-minute physical activity compared to a baseline assessment (Stein et al., 2017). Another found no differences in preschooler's task-based executive functions following a 15-minute sedentary task compared to an active one for preschoolers (Tandon et al., 2018). These findings stand in contrast to other experimental findings demonstrating immediate, positive impacts on task-based self-regulation for children of elementary school age (Best, 2010; Donnelly et al., 2016), even as both studies used structured tasks to ensure that children engaged in physical activity.

Although the evidence for immediate effects of preschoolers' activity on their task-based self-regulation appears limited, the impact of physical activity interventions appears more promising for their classroom-based self-regulation. A review of studies examining children's on-task behaviors following physical activity breaks indicated favorable effects in the small to moderate range (Mahar, 2011). Similarly, preschoolers demonstrated better attention (measured as on-task behaviors) following a ten-minute activity break led by classroom teachers, with an added benefit when this break incorporated physical movement and activity (Webster et al., 2015). This suggests that the timing of children's physical activity might matter more for their classroom-based self-regulation than for their task-based self-regulation.

Although intervention studies in early childhood settings are instructive, any differences that they document in children's self-regulation arise from structured activities led by study staff or classroom teachers. These structured activities may be difficult for teachers in early childhood classrooms to implement without proper supports. It is therefore important to understand whether differences in children's self-regulation also emerge following unstructured, child-led activities that naturally incorporate physical activity, such as outdoor play. This sort of naturalistic approach aligns with calls from developmental researchers to examine children's self-regulation in the regular contexts in which they must enact them (Jones et al., 2016; McClelland & Cameron, 2012). To our knowledge, only one study has linked preschoolers' self-regulation to their objectively measured physical activity during unstructured free play in their regular school context. Findings showed that children exhibiting higher levels of activity also had higher levels of inhibitory control (Becker et al., 2014). The assessment of children's self-regulation, however, preceded the measurement of physical activity, undermining the temporal precedence necessary to infer causality. Examining children's activities directly prior to the assessment of self-regulation would provide stronger evidence linking physical activity to children's outcomes. Examining a wider range of self-regulation skills, including those observed in task- as well as classroom-based activities, would provide a fuller picture of children's responses to outdoor play and physical activity.

The current study aimed to provide this set of within-child contrasts in a naturalistic frame, examining children's task-based and classroom-based self-regulation both before and after their unstructured outdoor play time and noting the amount of physical activity in which they engaged. Partnering with classroom teachers, we varied the timing of children's outdoor play, observing children's self-regulation on days in which they had already been outside to play compared to days when they had first engaged in indoor activities.

THE CURRENT STUDY

This study had three aims. The first was to examine whether the timing of children's outdoor play impacts their subsequent self-regulation. The second was to examine whether this relation was moderated by children's age, gender, and temperamental levels of self-regulation. The third aim was to assess whether the amount of physical activity in which children engage during outdoor play predicts their subsequent self-regulation. We examined children's self-regulation both via structured tasks and during regular classroom activities (i.e. behaviors indicating attention and inhibitory control), as well as how temperamental aspects of children's self-regulation (teacher reports) could moderate the relations.

We aimed to test three hypotheses consistent with developmental theory and empirical evidence reviewed above:

Hypothesis 1: Children will show higher levels of task-based and classroom-based self-regulation following outdoor play compared to following indoor activities.

Hypothesis 2a: Children who have lower levels of temperamental inhibitory control as rated by their teachers will show better task-based and classroom-based self-regulation following indoor classroom activities.

Hypothesis 2b: Children who have lower levels of temperamental inhibitory control as rated by their teachers will show better task-based and classroom-based self-regulation following outdoor play.

Hypothesis 3: Children who engage in higher levels of physical activity outdoors will demonstrate higher levels of task-based and classroom-based self-regulation following outdoor play time compared to children who do not.

Given prior empirical evidence, we hypothesized that differences in children's classroom-based self-regulation would be more likely to emerge than differences in their task-based self-regulation for Hypothesis 1 (Tandon et al., 2018; Webster et al., 2015). Hypothesis 2a and 2b were exploratory, as theory led us to believe that moderation by children's temperamental levels of self-regulation could predict either hypothesized outcomes. We developed Hypothesis 3 based on prior empirical evidence showing the positive impact of physical activity on task-based self-regulation in elementary-aged children (Best, 2010; Donnelly et al., 2016). We therefore expected differences to be more likely in children's task-based self-regulation compared to their classroom-based self-regulation when examining Hypothesis 3.

Methods

This study took place at a university-based laboratory school in the southwest United Sates that offers half-day preschool programs for children ages 3-5 and a full-day kindergarten program for children ages 5-6. This setting is accredited by the National Association for the Education of Young Children and as part of regular practice incorporates frequent classroom observations to promote undergraduate learning. Partnering with this laboratory school allowed for a rigorous naturalistic study in which we were able to introduce exogenous variation in the timing of children's outdoor play and physical activity and observation of children's behavior in their regular routines.

SAMPLE

All children enrolled in preschool or kindergarten classrooms were eligible for participation in this study. Of the 80 eligible children, we received parental consent from 73 children (91%) across five classrooms. One child was absent from school during all data collection times, bringing the full analytic sample to 72. We observed classroom-based self-regulation for all children with parental consent and collected teacher ratings of their temperament. Children were allowed to decline participation in assessments of task-based self-regulation and physical activity, resulting in different levels of participation across these aspects of the study. The flowchart in Figure 1 describes these differences.

Descriptive statistics for children participating in the study are shown in Table 1. Children were about 4.5 years old, on average, and 46% were female. Children's race/ethnicity was available for 67 children, 73% of children of whom were non-Hispanic white. Household income was available for 70 children, and roughly two-thirds (67%) of children came from families earning more than $150,000 per year. This compares with a median household income of $96,000 for fiscal year 2019 in the surrounding census-designated metro statistical area.

PROCEDURE

Children were assessed on two occasions over a six-week period in the fall of 2019. We assessed children's self-regulation after they had engaged in indoor classroom activities (study condition 1) and after they had engaged in 60 minutes of outdoor play (study condition 2). Teachers in the half-day preschool classrooms agreed to alter their schedules for a two-week period to allow us to observe children in both conditions. This was because their regular half-day schedules allowed us to observe children in one study condition but not both (see Table 2). For example, children in the 3-4 year-old classrooms regularly began their school day with indoor activities and ended their day with outdoor play, meaning we could not assess their self-regulation following outdoor play. Children in the 4-5 year-old classrooms began their school day with outdoor play, meaning we could not assess their self-regulation prior to outdoor play. The regular schedule for the full-day kindergarten allowed for both study conditions, so they did not alter their schedule for data collection.

The daily classroom schedules and corresponding study activities are shown for the half-day preschool and full-day kindergarten classrooms in Appendix 1. Observations of classroom-based self-regulation that occurred following outdoor play took place within 30 minutes of the end of outdoor play. One-on-one assessments of children's task-based self-regulation that took place after outdoor play followed the circle time observations and occurred within 30-60 minutes of the end of outdoor play.

These scheduling features allowed us to examine children's self-regulation following indoor activities and following outdoor play while ensuring the study remained naturalistic, that is, that it occurred in the children's regular school environment. This allowed for within-child comparisons of self-regulation, enhancing internal validity by eliminating confounding factors at the child-level. The naturalistic element of the study means that our findings will translate to other early childhood educational settings more easily than if they came from a lab setting.

MEASURES

To explore how outdoor physical activity matters for children's task- and classroom-based self-regulation, we collected data using a variety of methods including wearable activity-tracking devices, direct assessments, observational measures and questionnaires completed by classroom teachers.

Wearable activity trackers

Children participating in the study wore small, lightweight devices with accelerometer technology to log the amount of activity they engaged in while at school. These devices (*Actigraphs*) are widely used in studies of human activity and movement (Cain et al., 2013). The device is lightweight and the size of a small matchbox. The child's parent or classroom teacher attached the device comfortably around the child's waist and on top of their clothes at the beginning of the school days. The device does not impede movement and has no interface providing feedback to participants or data collectors in the field. To minimize any novelty effect that could impact children's activity levels, we collected pilot data with the children, allowing them to get used to the devices, but excluded these data from analysis.

The devices record movement on three axes by detecting changes in acceleration values across three-dimensional space, making them sensitive to movement across the many types of physical activities (e.g., sitting, running, jumping). The devices were set to record data in 1-second intervals. In order to convert the raw movement data from the triaxial accelerometers to intensities of physical movement, we collapsed the data into 15 second intervals to use the calibration method developed by Pate and colleagues (2006). In that study, children's raw acceleration values from Actigraph devices were aligned with children's volume of oxygen consumption during tasks of known physical intensity (e.g. sitting, brisk walking, jogging). For children of preschool age, Pate and colleagues determined that raw movement values in the range of 420-821 per 15 seconds represent moderate physical activity (3 – 5.9 metabolic equivalent tasks (MET)) and that movement values of 842 or greater per 15 seconds represent vigorous physical activity (>6 METs).

In this study, we used the accelerometer data to examine the amount of physical activity that children engaged in during their outdoor play time. After determining whether each 15-second period during children's outdoor play time indicated moderate or vigorous physical activity, we summed the number of minutes spent in moderate or vigorous physical activity. We then divided this sum by the total number of minutes that the child wore the device during outdoor play, yielding the percentage of time in MVPA. Children arrived at school at slightly different times and therefore did not all wear the Actigraph devices for the same amount of time. To ensure comparability of values across children with different amounts of wear-time, all analyses use children's percentage of wear-time in MVPA during their 60 minutes of scheduled outdoor play. We also employed commonly used wear-time validation procedures to discard periods for which we are confident that children did not wear devices (i.e., an extended period of 0-values; Vanhelst et al., 2019)).

Task-based assessments of self-regulation

We assessed children's self-regulation using three brief, game-like tasks that are widely used in preschool settings. Each assessment targets a specific component of self-regulation. Following an introduction from classroom teachers, we conducted the assessments one-on-one with the children in a quiet hallway of the school building, an area familiar to the children.

The first measure assessed *inhibitory control* (Head, Shoulders, Knees, and Toes; Ponitz et al., 2009). During this assessment, children must enact a behavior that is the opposite of what an assessor prompts them to do, such as touching their toes when the assessor says to touch their head and touching their knees when the assessor says to touch their shoulders. This task consisted of 30 items, with children receiving a score of 2 for a correct response, 1 for an incorrect response that children self-corrected, and 0 for an incorrect response. Thus, possible scores ranged from 0-60. This task has been used successfully with children ages 3-5 (e.g., Becker et al., 2014; Howard et al., 2019).

The second measure, assessing *shifting* (also called cognitive flexibility), was the Dimensional Change Card Sort task (DCCS; Zelazo, 2006). In this activity, children received a stack of cards and were instructed to sort them, first according to color, and then according to shape (the "post-switch trial"). Following successful completion of this post-switch trial, children sorted cards with rules that changed according to whether or not the card had a border around it. We scored this assessment according to whether children successfully completed the post-switch trials (that is, sorted 5 or more of the 6 cards correctly in this round). A score of 1 indicated successful completion and a score of indicated 0 indicated unsuccessful completion. This task has been successfully used in children of preschool age (e.g., McKinnon & Blair, 2019).

The third task was an assessment of *working memory,* the Backward Digit Span. This task prompts children to listen to a string of numbers and recall them in reverse order. Each round becomes progressively more difficult, and the assessment ends when children incorrectly recall the numbers in three consecutive rounds. This task is based on the Numbers Reversed task of the Woodcock-Johnson III Cognitive Battery (Schrank, 2011) and has been used successfully with children ages 3-5 (Chang et al., 2014; Montoya et al., 2019)

We assessed inter-rater reliability on roughly one-third (35%) of all the task-based self-regulation assessments using Cohen's kappa, a marker of agreement between raters that adjusts for expected agreement based solely on chance (Cohen, 1960). Reliability across raters was excellent for the Head, Toe, Knees, Shoulders task ($\kappa = .88$), the Dimensional Change Card Sort ($\kappa = .94$), and the Backward Digit Span ($\kappa = .99$).

Observations of classroom-based self-regulation

To understand how children regulated their behavior during regular classroom activities, we conducted observations using the *Regulation Related Skills Measure* (RRSM; McCoy et al., 2017). This tool measures the frequency with which children demonstrate specific behaviors that indicate the enactment of self-regulation skills within children's classroom settings. In contrast to other observational tools that capture the degree to which young children engage in regulated behaviors during structured activities or assessments, such as the *Preschool School Readiness Assessment (PSRA*; Smith-Donald et al., 2007) and the *Preschool Situational Self-Regulation Toolkit* (*PRSIST*; Howard et al., 2019), the *Regulation-Related Skills Measure* is unique in that it examines children's behaviors during regular classroom activities.

The scoring protocol calls for observing children's behavior for a five-minute period and providing a global rating for each of 16 items that target specific behaviors indicating different self-regulatory skills such as attentional or inhibitory control. The item scoring employs a Q-sort method in which coders first decide whether a child mostly does or does not display the behavior during the given period. Following this decision, the coder then decides whether the child did or did not consistently or most of the time. Scores range from 1 to 4 with higher scores indicating more consistent displays of the behavior in the classroom context (1 = does consistently, 2 = does most of the time, 3 = most of the time does not, 4 = consistently does not). Coders rely on a set of anchor behaviors set forth in the user's guide that describe the behaviors that young children might display that indicate enacting or not enacting the items (see Appendix 2).

The original measure was originally developed using video coding, and we adapted the measure to use with live coding. This was because we could not secure the proper permissions to video record the whole classroom, which would have included children whose parents did not consent to their children's participation in the study. To adapt to live coding, we reduced the number of items to code from sixteen to seven. We chose seven items from this measure to capture children's attention and inhibitory control. The original measure has 16 items that assess a broader range of skills, but we elected to limit the number of items in order to reduce the cognitive burden in live coding and increase accuracy and reliability. We chose three items that indicated behaviors related to attentional control: "pays attention to the task at hand," "ignores distractions during an activity," and "shows evidence of listening." We also chose four items indicating behaviors related to inhibitory control: “controls physical movements,” “follows classroom rules and routines independently,” “inhibits inappropriate or automatic responses and enacts appropriate responses,” and “is able to wait for something.” During the training of research assistants, the behaviors indicating the item “is able to wait for something” were not frequently observed during our observations, so we excluded this item from subsequent coding. Thus, the final observation scale included six items.

A main graduate coder involved in the development of the RRSM trained undergraduate coders to conduct observations in two stages. First, they watched video clips of preschool children engaging in circle time classroom activities, such as listening to a teacher read a book or singing a daily song. The graduate coder highlighted specific behaviors that children displayed and how to code them using the RRSM protocol. This was an iterative process during which coders discussed behaviors, coding decisions, and resolved discrepancies in coding. In the second stage, coders observed children during their classroom circle time to practice live coding. This was also an iterative process during which coders discussed and resolved discrepancies following the observations. The training took place over a four-week period.

For observations used in the analyses, trained graduate and undergraduate coders rated the frequency with which children engaged in behaviors related to attentional control and inhibitory control during circle time. A daily circle time is routine in many early childhood education centers and is an activity in which the whole class gathers to engage in a lesson, listen to a story, or sing songs. In contrast to center-based activities, circle time is directed by the classroom teacher and operates under a narrower set of behavioral expectations. During circle time children are expected to remain seated in their spot, maintain their “bubble space” and keep their hands to themselves, to listen and not interrupt while others are talking, to raise their hand before speaking, to pay attention to the activity, to refrain from talking to their neighbor, and to avoid engaging with objects in their surroundings.

We conducted observations during circle time because the expectations for children’s behaviors are well-defined and because it is a relatively standard activity from day-to-day and across classrooms. The concrete and standardized expectations during this period gave us greater confidence that we could interpret children's behaviors as indicating paying attention and inhibiting inappropriate automatic responses. Two coders observed the behavior for each child during a 5-minute observation period, timed using stopwatches, and gave global ratings for each item for the period observed during a one-minute scoring period.

We assessed inter-rater reliability using intraclass correlations for the RRSM rating subscales (Shrout & Fleiss, 1979). Coders were considered reliable if their individual intraclass correlations with a main graduate student coder were greater than or equal to .5. When codes from two reliable raters were available, we averaged the score of these raters (41% of observations). When codes were available from only one reliable coder, we used the individual scores from the reliable raters (50%). A small number of observations had codes from two unreliable raters, and these were excluded from analyses (9%) in order to retain adequate inter-rater reliability. The final inter-rater reliability for codes used in analysis was calculated using a combination of individual and average intraclass correlations (ICCs) because the codes used in analysis were taken both from individual raters and from the average of two raters. We weighted each coder's ICC according to the proportion of scores that came from each coder. The ICCs for raters contributing to data used in analyses were .73 for attentional control and .75 for inhibitory control.

Because we used a subset of items from the original RRSM, we tested the factor structure reported in a previous study (Koepp et al., 2019) which indicated separate subscales for behavioral regulation related to attentional control and inhibitory control. A confirmatory factor analysis using Mplus 8 confirmed that a two-factor structure fit better than a one-factor structure in this sample ($p < .001$), validating the decision to examine attention and inhibitory control separately. Internal consistency was high for items capturing classroom-based self-regulation related to attention ($\alpha = .92$) and inhibitory control ($\alpha = .89$).

Temperament-based self-regulation

Teachers provided global ratings of each child's overall level of physical activity, attention, and impulsive behavior. We selected five items from each of these three domains in Rothbart and Putnam's (2006) *Child Behavior Questionnaire*, a measure of children's temperament, retaining items relevant to the classroom setting. We limited the questionnaire to these 15 items to reduce the burden of response on classroom teachers, who completed the questionnaire for each child in their classroom. The scale ranged from 1 "Not at all true" to 5 "Extremely true. " Internal consistency was adequate for each subscale including physical activity ($\alpha = .85$), for attentional control ($\alpha = .87$), and for inhibitory control ($\alpha = .91$).

ANALYTIC APPROACH

Our analytic approach reflected the three aims of the study: examining the impact of the timing of children's outdoor play on their self-regulation, examining moderation of that impact by children's age, gender, and temperamental levels of inhibitory control, and examining how the amount of physical activity in which children engaged predicts their self-regulation.

Timing of Outdoor Play

To assess the impact of the timing of children's outdoor play, we used a series of multi-level regression models (Raudenbush & Bryk, 2002) with two observations nested within children. The primary predictor was a dichotomous indicator of whether or not the assessment or observation occurred prior to or following children's outdoor play. A value of 1 indicated the assessment or observation occurred after outdoor play and a value of 0 indicated that the assessment or observation occurred before outdoor play. We used linear regression models with robust standard errors to account for the non-normal distributions in the HTKS task, backward digit span, and classroom observations of attention and inhibitory control. We used a logistic regression equation to predict the log-odds of successful completion of the post-switch trial of the DCCS. All regression models controlled for a child's age, gender, classroom, and teacher ratings of children's temperamental inhibitory control. Teacher ratings were identified as an important covariate, as they were related both to children's activity levels and their self-regulation and could potentially confound the relationship between them.

We probed for potential differences in the impact of the timing of children's outdoor play according to child characteristics. Multi-group analyses were used to examine whether the impacts were different for boys versus girls as well as for children in younger classrooms (3-4 year old classrooms) compared to those in older classrooms (4-5 year old classrooms and Kindergarten classrooms). We hypothesized potential differences because behavioral expectations might vary for different classrooms based on children's developmental stage. We also tested the interaction of outdoor play and physical activity with the teacher's rating of inhibitory control, as physical activity may most benefit the children who struggle to enact executive function and behavioral regulation (Drollette et al., 2014).

Children's amount of physical activity

The second set of analyses examine children's self-regulation after playing outside, using the amount of moderate to vigorous physical activity in which they engaged as the primary predictor. Thus, these present between-child differences, in contrast to the finding above. These analyses used ordinary least square regression with robust standard errors and logistic regression depending on the outcome.

Accelerometry data were missing for the 20 out of 69 children who participated in the outdoor play condition (29%). Data were missing because 11 children elected not to wear the devices during this study condition (55% of missing cases), 4 had valid wear-time less than 20 minutes (20% of missing cases), and 5 had device malfunctions recording zero values despite valid wear-time (25% of missing cases), indicating either device malfunction or human error.

We handled missing accelerometry data in two ways in order to probe sensitivity to either approach. First, we ran the analyses using the sample with available data. Second, we conducted multiple imputation across 200 datasets for missing values of children's percentage of time engaged in moderate to vigorous activity. Multiple imputation of missing data is a preferred method for handling missing data because it reduces potential bias in estimates that arising from missing cases (Enders, 2013). We imputed these values using a truncated regression equation in Stata version 16 (StataCorp, 2019) that restricted imputation values to be within the range observed in the sample (i.e., 5.17-62.8%). This restriction prevented the imputation of out-of-bound values, such as percentages below zero.

Results

We first compared children's self-regulation on days when they had first engaged in 60 minutes of outdoor play to their self-regulation on days when they had first engaged in indoor activities. We examined both their task-based self-regulation via one-on-one assessments and their classroom-based self-regulation through observations during classroom circle time. Descriptive statistics for the task-based and classroom-baesd self-regulation are presented by study condition in Table 3. A correlation matrix of key study variables is shown in Table 4.

DIFFERENCES IN TASK-BASED SELF-REGULATION FOLLOWING OUTDOOR PLAY

Children did not show differences in task-based self-regulation on days when they had first been outside to play for 60 minutes compared to those when they had not. These null results are presented in Table 5 for inhibitory control (HTKS), shifting (DCCS: post-switch trial), and working memory (BDS). Children in the 3-4 year old classroom showed a trend toward better inhibitory control (HTKS; $p = .05$; see Table 5) but did not show improvements for shifting (DCCS) or working memory (BDS). The difference in inhibitory control appeared to be larger for children who showed higher temperamental levels of inhibitory control as reported by their teachers ($p < .05$; see Table 6). This difference did not emerge for children in the 4-5 year old and kindergarten classrooms after controlling for potential practice effects (see Table 5). Evidence of such moderation by temperament did not emerge for shifting or working memory in this age group (see Table 6). There was also no evidence of moderation by child's gender (see Table 7).

DIFFERENCES IN CLASSROOM-BASED SELF-REGULATION FOLLOWING OUTDOOR PLAY

In contrast to children's task-based self-regulation, their classroom-based self-regulation showed differences following a 60-minute period of outdoor play (see Table 8). Children's attention in the classroom was .34 standard deviations higher after they had played outdoors compared with after they had stayed inside first, after controlling for covariates ($p < .05$). The estimate for children's inhibitory control in the classroom also indicated differences favoring the outdoor play condition, those these were not statistically significant.

When broken out by age, children in the 3-4 year old classrooms showed positive differences both in attentional regulation (.44 SDs, $p < .01$) and inhibitory control in the classroom (.33 SDs, $p < .01$; see Table 8). Children in the 4-5 year old and kindergarten classrooms also showed positive differences in their attention regulation (see Table 8), though these estimates were less precise and significant only at the trend level (.53 SDs, $p = .07$), suggesting they might be under-powered. The estimate for behavioral inhibition was also positive, but not statistically significant. We did not find evidence of moderation by temperament of these effects by age group (see Table 9) or by gender (see Tables 10).

SELF-REGULATION AND ENGAGEMENT IN PHYSICAL ACTIVITY DURING OUTDOOR PLAY

Descriptive statistics for children participating in the outdoor play condition are presented in Table 11. Children wore the accelerometer devices for an average of 53 minutes during their regular 60 minutes of unstructured outdoor play. On average, children spent about 25% of the time in moderate to vigorous physical activity (MVPA), though this ranged from about 5% to about 63%.

Children's percentage of time in MVPA during outdoor play showed quadratic relationships with their task-based self-regulation when including cases from multiply imputed datasets (see Table 12). That is, they showed positive linear slopes and negative quadratic slopes (indicating an inverted U-shape) for inhibitory control (HTKS; $p < .05$) and for shifting (DCCS; $p < .05$). A similar pattern emerged for working memory (BDS), though the estimates were not statistically significant. When excluding cases from the multiply imputed datasets, the quadratic relationships attenuated slightly (see Table 12) and were significant at the trend level for inhibitory control (HTKS; $p = .07$) and for shifting (DCCS; $p = .09$).

The regression equations estimated for each task-based self-regulation component imply a consistent maximum for executive function and MVPA, both when using the multiply imputed datasets (see Figure 2) and when excluding them (see Figure 3). That is, children with the best task-based self-regulation, holding covariates constant, had spent around 25-30% of time their time in outdoor play in MVPA. This was true for children’s inhibitory control, shifting, and working memory. A fairly wide range of time spent in MVPA still predicted better task-based self-regulation (15-40%), but worse performance on task-based self-regulation tasks was predicted for children who engaged in less than 10% and more than 50% of time in MVPA.

Children’s classroom-based self-regulation showed neither linear nor quadratic relationships with children’s percentage of time in MVPA (linear regression estimates are shown in Table 13).

Discussion

This study found differences in preschoolers' classroom-based self-regulation following a 60-minute period of unstructured outdoor play. These impacts emerged most clearly for children in younger classrooms, and though older children showed similar estimated benefits, these estimates were less precise despite the larger sample size. Overall, we found a generalized effect such that children showed more greater attention and behavioral inhibitory control following outdoor play and a transition indoors. These results are consistent with results from a study showing improvements in children's on-task behaviors following active classroom breaks (Webster et al., 2015). The null results for within-child differences for task-based self-regulation are consistent with other experimental studies. Tandon et al. (2019) examined preschoolers' task-based self-regulation following 15 minutes of a sedentary versus a 15-minute, structured active condition, finding little evidence for within-child differences. This raises the question as to why differences would emerge for classroom-based self-regulation but not for task-based self-regulation.

The difference may arise from the different contextual demands present in classroom observations compared to one-on-one assessments (McCoy, 2019). The way that children enact behaviors related to attention and inhibitory control when in the classroom, among peers and competing distractions, could be very different from the same child employing executive functions in an affectively neutral cognitive task (McClelland & Cameron, 2012). The idea that children's observed behavior depends on their immediate social context is supported by theoretical work describing "dynamic microprocesses," a series of ongoing, immediate transactions between an individual and his/her environment (Olson & Lunkenheimer, 2009). Exploratory empirical work has noted within-child differences in young children's behavioral self-regulation across different activities in the classroom (Koepp et al., 2019).

Supporting children in enacting self-regulation in the classroom could prepare them to manage their behavior at school entry. This would be an example of how proximal processes accumulate to drive development (Bronfenbrenner & Morris, 2006). Children may need the challenge of a context with competing demands, like the classroom circle times observed in this study, to learn the skills for inhibiting automatic responses and focusing their attention in real-world settings. Identifying factors that promote the development of these behavioral skills is an important policy goal (Blair & Raver, 2015), as deficits in classroom-based self-regulation at kindergarten predict less growth in reading in first grade (Moffett & Morrison, 2019). Thus, findings from the current study suggest that the strategic timing of children's outdoor play can support the enactment of behaviors that promote children's academic skills.

Beyond the timing of outdoor play, the amount of physical activity in which children engaged also appeared to play a role in children's task-based self-regulation, as suggested by our second set of analyses. We found that children who engaged in a moderate amount of moderate to vigorous physical activity during 60 minutes of unstructured outdoor play showed the most self-regulation via tasks, while those who engaged in lower or higher amounts showed lower levels of task-based self-regulation. This pattern held for each skill assessed (inhibitory control, shifting, and working memory), with each component showing a quadratic relationship and a consistent "sweet-spot" between 25-30% of time in MVPA. This value of 25% aligns well with national recommendations that children engage in 3 hours of light, moderate, or vigorous physical activity per day (U.S. Department of Health and Human Services, 2018) or 15 minutes of light, moderate, or vigorous physical activity per hour while they are in early childhood education settings (Institute of Medicine, 2011). These guidelines were developed with a goal to reduce childhood obesity and promote physical health, but our findings suggest that this target could also benefit children's cognitive health. This possibility is underscored by work showing the close interrelation of cognitive and physical development (Diamond, 2000, 2007).

To our knowledge, this is the first study to find a quadratic relationship between children's time in MVPA and their subsequent task-based self-regulation . Though these findings should be interpreted as exploratory, they fit with other recent findings linking children's physical activity to subsequent cognitive processing. Although empirical work in early childhood remains scarce (Carson et al., 2016), studies have shown fairly consistent benefits of physical activity in school settings for the cognitive functioning in elementary-aged children (Donnelly et al., 2016). There are reasons, however, to think that levels of physical engagement that are too high in early childhood might be associated with poorer cognitive functioning (Howard et al., 2016). Recent work has described an energetic tradeoff between brain and body in early childhood (Blair et al., 2020; Kuzawa & Blair, 2019). As the brain accounts for a lifetime maximum of glucose consumption during this period, there may be greater competition between the brain and the body for resources (Kuzawa et al., 2014). As employing task-based self-regulation is cognitively demanding, and the skills are still developing in early childhood (Best & Miller, 2010), the ability to enact them may be limited following energy expenditure in high levels of MVPA during outdoor play.

Another explanation for this pattern, namely the reversal of benefits at higher-than-average levels of physical activity, may be that children who engage in high levels of MVPA simply have lower overall levels of executive function. This explanation fits with empirical findings that preschoolers' weekly amounts of vigorous physical activity is associated with lower task-based self-regulation (Willoughby et al., 2018). We cannot rule out this possibility in the current study because we did not observe within-child differences in task-based self-regulation following different levels of physical activities, but future studies should explore this area.

IMPLICATIONS

The naturalistic approach of this study enhances generalizability to preschool classroom settings. These findings have high ecological validity given that children participated in outdoor play in their regular school setting and no interventions were made to their physical activity. Children's outdoor play took take place on children's regular playground, and the observations occurred during their normal circle time as part of their classroom routine. The one-on-one assessments took place in a quiet hallway a familiar area of the school building. Findings from this environment will generalize more easily to educational settings than if the study were conducted in a lab setting unfamiliar to the children.

Notable for practitioners is that the highest levels of task-based self-regulation occurred following a fairly wide range of time spent in MVPA, with the greatest benefit occurring between 25-35%, and with roughly 60% of the maximum benefit still occurring in the range from 10-45% MVPA. This also appears to be the range of activity which most children in the sample engaged naturally, suggesting that without physical activity interventions, young children might naturally engage in a level of MVPA associated with better cognitive functioning. Future studies with larger samples should try to replicate these findings.

Although children's engagement in this range of MVPA occurred without structured or adult-led interventions to promote physical activity, it is possible that this level of activity depends on the outdoor play setting. The setting for this study was highly enriched with natural areas for imaginative play and opportunities to engage gross motor skills. Such opportunities or combinations of opportunities could influence the amount of physical activity in which children engage. One study found that children in Montessori programs are more active than those in traditional preschool programs (Pate et al., 2014), while another documented a general lack of opportunities for active play in most preschool programs (Tandon et al., 2015). The setting for this study provided 60 minutes of outdoor play children in each classroom, which is a good deal higher than the average of 37 minutes per day across Head Start centers (Ansari et al., 2015). Future research should examine whether similar cognitive benefits occur in settings with less enriched outdoor areas or with less time for outdoor play.

Strengths and Limitations

A strength of this study is the quasi-experimental design to examine within-person differences, which eliminated potential confounds at the child level for examining the impact of the timing of children's outdoor play. Another strength is that the link between children's self-regulation and the amount of physical activity in which they engaged was measured objectively using accelerometer data. The observation of children's classroom-based self-regulation brought a high level of ecological validity because we observed children during their regular classroom routines.

These observations did present some measurement challenges, however, including a ceiling effect for children's on-task behaviors. Other studies have described similar ceiling effects for children's on-task behaviors (Koepp et al., 2019; Moffett & Morrison, 2019), indicating that most children most of the time may not show sustained or substantial deviations from expected levels of attention or inhibitory control in their classrooms. The presence of such a ceiling effect, however, may mean that our measurement of classroom-based self-regulation was more sensitive to more serious or more obvious deviations in behavior rather than smaller deviations. From a perspective of classroom management, however, it may be precisely the larger deviations in attention and inhibitory control that teachers most care about, as they are most likely to be most disruptive to other students. For this reason, we believe our findings are relevant for practice despite the ceiling effect.

Another challenge in measuring children's classroom-based self-regulation was establishing inter-rater reliability. Not all observers met reliability benchmarks, and because this project used live-coding in classrooms rather than video coding, we could not go back and re-code children's behaviors. We adapted to this challenge by having two coders conduct each observation, but nevertheless had to exclude a small amount of data from analyses to retain high inter-rater reliability. The coders showing highest inter-rater reliability were those who had experience working or volunteering in early childhood education settings and were familiar with behavioral expectations in this setting with children of this age. One final limitation of the observations conducted in this study is that coders were not blind to the research question, and though we did not explicitly tell observers which condition each child was in on each day, they were also not explicitly blinded to these conditions. Future research should consider blinded procedures to enhance rigor.

A final measurement challenge came in assessing working memory. Although the backward digit span has been used successfully with kindergarteners, it was too difficult for the youngest children in our sample, which has been reported in other studies (Lipsey et al., 2017). This created a floor effect in the overall sample when examining working memory specifically.

Collecting the accelerometry data also presented challenges. Some children simply did not feel comfortable wearing the devices, and at times human error or device malfunction resulted in missing data. We addressed these challenges by using multiple imputation to ensure that our results were not biased by excluding missing information (Enders, 2013).

Conclusion

This study showed differences in children’s classroom-based self-regulation following 60 minutes of unstructured outdoor free play, with the greatest benefit for 3 to 4 year-olds. Children’s task-based self-regulation did not show similar within-child differences following outdoor play, but children who engaged in moderate amounts of moderate to vigorous physical activity showed greater task-based self-regulation than did children who engaged in very low or very high amounts. The range of MVPA predicting the best performance on subsequent tasks aligned with guidelines from the Institute of Medicine for promoting young children’s health. Our results suggest that children’s classroom-based self-regulation may depend on opportunities for outdoor play while their task-based self-regulation may depend on the amount of physical activity in which children engage during that outdoor play.

Tables and Figures

Table 1. Descriptive Characteristics of Study Participants (*N* = 72)

Child Characteristics	Mean (SD)/%	Range
Age (years)	4.42 (.77)	3.15 - 6.10
Female	46%	-
Teacher-rated temperament		
Attentional control	3.74 (.99)	1.2 - 5
Inhibitory control	3.92 (1.07)	1 - 5

Table 2. Classroom Schedules and Study Conditions

	Regular schedule	Altered schedule
3-4 Year-Old Classrooms	Study Condition 1	Study Condition 2
4-5 Year-Old Classrooms	Study Condition 2	Study Condition 1
Kindergarten Classroom	Study Condition 1 & 2	-

Note: Study Condition 1 = Indoor classroom activities precede assessment of self-regulation, Study Condition 2 = Outdoor play precedes assessment of self-regulation.

Table 3. Descriptive Statistics for Children's Task-Based and Classroom-Based Self-Regulation, by Study Condition

	Before Outdoor Play	After Outdoor Play	Overall
Task-based self-regulation (*N* = 138)	Mean (SD)/%	Mean (SD)/%	Mean (SD)/%
Inhibitory control (HTKS)	28.36 (23.10)	28.01 (21.00)	28.19 (21.99)
Shifting (DCCS)	71%	72%	72%
Working memory (BDS)	2.59 (3.44)	2.32 (3.27)	2.46 (3.34)
Classroom-based self-regulation (*N* = 127)			
Attention (observed)	3.44 (.62)	3.63 (.59)	3.53 (.61)
Inhibitory control (observed)	3.52 (.65)	3.66 (.57)	3.59 (.61)

Note: HTKS = Head, Toes, Knees, Shoulders ; DCCS = Dimensional Change Card Sort (post-switch trial); BDS = Backward Digit Span

Table 4. Correlation Matrix of Key Study Variables

	1	2	3	4	5	6	7	8	9
1. After outdoor play	1								
2. Inhibitory control (HTKS)	-0.01	1							
3. Shifting (DCCS)	0.02	0.49***	1						
4. Working memory (BDS)	-0.04	0.63***	0.36***	1					
5. Attentional control (observed)	0.16~	0.15~	0.17~	0.10	1				
6. Inhibitory control (observed)	0.10	0.12	0.20*	0.05	0.86***	1			
7. Teacher-rated attentional control	0.00	0.07	0.17*	-0.02	0.26**	0.37***	1		
8. Teacher-rated inhibitory control	0.00	0.11	0.24**	0.02	0.41***	0.54***	0.86***	1	
9. % Time in MVPA	-	-0.06	-0.09	0.22	0.19	0.12	-0.24	-0.22	1

Note: ~ p < 0.1, * p < .05, ** p < .01, *** p < .001

Table 5. Model Estimates of Within-Child Differences in Task-Based Self-Regulation before and after Outdoor Play

PANEL A: Full Sample (n = 138 observations, 71 children)						
	Inhibitory control (HTKS)		Shifting (DCCS)		Working Memory (BDS)	
	Est.	S.E.	Est.	S.E.	Est.	S.E.
After outdoor play	-0.14	1.55	0.21	0.55	-0.26	0.2
Teacher-rated inhibitory control	4.06*	2.01	.92*	0.45	0.47	0.29
Age (years)	19.30***	4.9	2.44˜	1.44	2.84**	0.85
Female	-2.15	3.83	1.26	0.86	-0.38	0.48
Constant	33.73***	5.71	3.16*	1.52	1.39	1.4
PANEL B: 3-4 Year Old Classrooms (n = 54 observations, 29 children)						
	Inhibitory control (HTKS)		Shifting (DCCS)		Working Memory (BDS)	
	Est.	S.E.	Est.	S.E.	Est.	S.E.
After outdoor play	5.40˜	2.81	1.03	1.14	0.24	0.2
Teacher-rated inhibitory control	-0.24	2.02	1.99	1.52	0.3	0.22
Age (years)	25.21***	6.13	1.62	3.22	1.13	0.74
Female	-7.67˜	-7.67	0.53	1.79	-0.81˜	0.42
Constant	20.04***	4.68	2.82	2.4	1.07**	0.4
PANEL C: 4-5 Year Old and Kindergarten Classrooms (n = 84, 42)						
	Inhibitory Control (HTKS)		Shifting (DCCS)		Working Memory (BDS)	
	Est.	S.E.	Est.	S.E.	Est.	S.E.
After outdoor play	-2.21	1.87	-0.1	2.1	-0.54	0.42
Practice effects	2.14	0.19	0.05	2.1	-0.03	0.42

Teacher-rated inhibitory control	4.94~	2.99	0.45	0.45	0.6	0.43
Age (years)	13.86*	6.64	2.46	1.71	3.78**	1.25
Female	2.39	5.92	2.29*	1.13	-0.16	0.76
Constant	32.98	7.93	0.36	4.23	3.45**	1.19

Table 6. Model Estimates for Moderation of Within-Child Differences in Task-Based Self-Regulation before and after Outdoor Play by Temperamental Levels of Inhibitory Control

PANEL A: 3-4 Year Old Classrooms (n = 54 observations, 29 children)						
	Inhibitory control (HTKS)		Shifting (DCCS)		Working Memory (BDS)	
	Est.	S.E.	Est.	S.E.	Est.	S.E.
After outdoor play	5.40*	2.68	1.04	1.16	2.37	0.19
Teacher-rated inhibitory control	-2.45	2.17	2.25	1.84	0.17	0.24
Interaction (outside x inhib)	4.67*	2.03	-0.4	1.26	0.27	0.18
Age (years)	25.36***	6.05	1.71	3.22	1.14	0.74
Female	-7.36~	4.42	0.53	0.19	-0.78	0.42
Constant	19.86***	4.71	4.22	3.98	1.06**	0.4
PANEL B: 4-5 Year Old and Kindergarten Classrooms (n = 84, 42)						
	Inhibitory Control (HTKS)		Shifting (DCCS)		Working Memory (BDS)	
	Est.	S.E.	Est.	S.E.	Est.	S.E.
After outdoor play	-2.2	1.87	-0.02	2.2	-0.54	0.41
Teacher-rated inhibitory control	5.69	3.2	0.15	0.55	0.52	0.47
Interaction (outside x inhib)	-1.51	1.89	0.66	0.67	0.17	0.3
Practice effects	2.19	1.89	0.07	2.2	-0.03	0.41
Age (years)	13.81*	6.63	2.59	1.8	3.78**	1.25
Female	2.4	5.92	2.37*	1.2	-0.16	0.76
Constant	25.84**	8.25	0.33	4.44	1.54	1.16

Note: ~ $p < 0.1$, * $p < .05$, ** $p < .01$, *** $p < .001$ HTKS = Head, Toes, Knees, Shoulders ; DCCS = Dimensional Change Card Sort (post-switch trial); BDS = Backward Digit Span; Inhib = Teacher-rated inhibitory control.

Table 7. Model Estimates for Moderation of Within-Child Differences in Task-Based Self-Regulation before and after Outdoor Play by Child Gender

PANEL A: Boys (n = 73 observations, 38 children)						
	Inhibitory Control (HTKS)		Shifting (DCCS)		Working Memory (BDS)	
	Est.	S.E.	Est.	S.E.	Est.	S.E.
After outdoor play	-0.58	2.59	-0.97	0.8	-0.39	0.31
Teacher-rated inhibitory control	5.60*	2.4	0.6	0.54	0.54	0.38
Age (years)	7.85	6.58	0.67	0.21	3.76**	1.21
Constant	27.42***	6.71	0.306	1.98	3.83**	1.35

PANEL B: Girls (n = 65 observations, 33 children)						
	Inhibitory Control (HTKS)		Shifting (DCCS)		Working Memory (BDS)	
	Est.	S.E.	Est.	S.E.	Est.	S.E.
After outdoor play	-0.02	1.66	-	-	-0.12	0.23
Teacher-rated inhibitory control	-1.95	2.76	-	-	0.41	0.39
Age (years)	26.13***	5.85	-	-	1.04	0.96
Constant	35.45***	8.27	-	-	1.01	0.86

Note: ~ $p < 0.1$, * $p < .05$, ** $p < .01$, *** $p < .001$ HTKS = Head, Toes, Knees, Shoulders ; DCCS = Dimensional Change Card Sort (post-switch trial); BDS = Backward Digit Span. Model for shifting (DCCS) did not converge.

Table 8. Model Estimates for Within-Child Differences in Children's Classroom-Based Self-Regulation before and after Outdoor Play

PANEL A: Full Sample (*n*=127 observations, 72 children)				
	Attention		Inhibitory Control	
	Est.	S.E.	Est.	S.E.
After outdoor play	0.21*	0.10	0.09	0.08
Attentional control (temperament)	0.17**	0.05	-	-
Inhibitory control (temperament)	-	-	0.32***	0.06
Age (years)	0.21	0.17	-0.03	0.14
Female	0.04	0.1	0.1	0.08
Constant	3.54***	0.34	3.57***	0.29
PANEL B: 3-4 Year Old Classrooms (*n*=54 observations, 29 children)				
	Attention		Inhibitory Control	
	Est.	S.E.	Est.	S.E.
After outdoor play	0.30**	0.1	0.21**	0.08
Attentional control (temperament)	0.00	0.11		
Inhibitory control (temperament)			0.33**	0.09
Age (years)	.65*	0.32	0.13	0.27
Female	0.03	0.17	0.19	0.15
Constant	3.49	0.44	2.19***	0.44
PANEL C: 4-5 Year Old and Kindergarten Classrooms (*n* = 73 observations, 43 children)				
	Attention		Inhibitory Control	
	Est.	S.E.	Est.	S.E.
After outdoor play	.30~	0.17	0.135	0.139
Attentional control (temperament)	.18**	0.06		
Inhibitory control (temperament)			.32***	0.069
Age (years)	0	0.14	-0.17	0.14
Female	0.09	0.11	0.034	0.097
Constant	3.32***	0.24	3.40***	0.185

Note: $^{\sim}$ $p < 0.1$, * $p < .05$, ** $p < .01$, *** $p < .001$

Table 9. Model Estimates Testing Moderation of Within-Child Differences in Classroom-Based Self-Regulation before and after Outdoor Play by Temperamental Levels of Self-Regulation

PANEL A: 3-4 Year Old Classrooms (*n* = 54 observations, 29 children)				
	Attention		Inhibitory Control	
	Est.	S.E.	Est.	S.E.
After outdoor play	.31**	0.1	.22**	0.08
Attentional control (temperament)	0.04	0.1		
Inhibitory control (temperament)			.30**	0.11
Interaction (Outside x Temperament)	-0.09	0.09	-0.05	0.08
Age (years)	0.64~	0.33	0.13	0.27
Female	0.04	0.17	0.2	0.15
Constant	3.49***	0.15	3.51	0.14
PANEL B: 4-5 Year Old Classrooms (*n* = 73 observations, 43 children)				
	Attention		Inhibitory Control	
	Est.	S.E.	Est.	S.E.
After outdoor play	.28˜	0.16	0.1	0.13
Attentional control (temperament)	.26**	0.08	-	-
Inhibitory control (temperament)	-	-	.41***	0.09
Interaction (Outside x Temperament)	-0.17	0.12	-0.2	0.14
Age (years)	-0.03	0.14	-0.19	0.13
Female	0.1	0.11	0.03	0.09
Constant	3.35***	0.212	3.58***	0.16

Note: ˜ $p < 0.1$, * $p < .05$, ** $p < .01$, *** $p < .001$

Table 10. Model Estimates for Within-Child Differences in Classroom-Based Self-Regulation before and after Outdoor Play by Child Gender

PANEL A: Boys (*n* = 69 observations, 39 children)				
	Attention		Inhibitory Control	
	Est.	S.E.	Est.	S.E.
After outdoor play	0.21	0.13	0.17	0.12
Attentional control (temperament)	.24***	0.06	-	-
Inhibitory control (temperament)	-	-	.28***	0.07
Age (years)	-0.03	0.2	-0.24	0.18
Constant	3.97***	0.28	3.63***	0.23
PANEL B: Girls (*n* = 58 observations, 33 children)				
	Attention		Inhibitory Control	
	Est.	S.E.	Est.	S.E.
After outdoor play	0.16	0.16	-0.03	0.14
Attentional control (temperament)	-0.11	0.09	-	-
Inhibitory control (temperament)	-	-	0.12	0.08
Age (years)	0.31	0.28	0.16	0.19
Constant	3.32***	0.55	3.75	0.38

Note: ~ $p < 0.1$, * $p < .05$, ** $p < .01$, *** $p < .001$

Table 11. Child Characteristics and Task- and Classroom-Based Self-Regulation following Outdoor Play

Child Characteristics (*N* = 69)	Mean (SD)/%	Range
Age (years)	4.45 (.77)	3.19 - 6.10
Female	46%	
Teacher-rated temperament		
Attentional control	3.71 (1.00)	1.2 - 5
Inhibitory control	3.90 (1.07)	1 - 5
Task-based self-regulation (*N* = 69)		
Inhibitory control (HTKS)	28.02 (20.98)	0 - 60
Shifting (DCCS)	73%	0 - 1
Working memory (BDS)	2.32 (3.27)	0 - 11
Classroom-based self-regulation (*n* = 58)		
Attention	3.66 (.52)	1.67 - 4
Inhibitory control	3.68 (.50)	1.75 - 4
Outdoor Physical Activity (*n* = 49)		
Wear-time minutes	52.71 (11.29)	22.25 - 60
% Time in MVPA	25.15% (12.39)	5.17% - 62.8%

Note: HTKS = Head, Toes, Knees, Shoulders ; DCCS = Dimensional Change Card Sort; BDS = Backward Digit Span; MVPA = Moderate to vigorous physical activity

Table 12. Models Estimating Association between Percentage of Time in MVPA and Task-Based Self-Regulation Functions following Outdoor Play

PANEL A: Imputed Datasets (*n* = 69)						
	Inhibitory Control (HTKS)		Shifting (DCCS)		Working Memory (BDS)	
	Est.	S.E.	Est.	S.E.	Est.	S.E.
% of Outdoor Time in MVPA						
Linear slope	1.32~	0.68	0.32*	0.16	0.11	0.08
Quadratic slope	-.025*	0.012	-.005*	0.003	-0.002	0.001
Teacher-rated inhibitory control	3.40*	1.49	0.62*	.28*	0.44~	0.23
Age (years)	19.59**	5.83	1.84	1.41	1.97~	0.93
Female	-3.81	4.17	1.92*	0.95	-0.35	0.53
Constant	26.35	9.43	-0.85	0.22	1.56	1.49

PANEL B: No Imputation of Data (*n* = 49)						
	Inhibitory Control (HTKS)		Shifting (DCCS)		Working Memory (BDS)	
	Est.	S.E.	Est.	S.E.	Est.	S.E.
% of Outdoor Time in MVPA						
Linear	1.72	0.72	0.28	0.17	0.1	0.09
Quadratic	-.02~	0.01	-.005~	0.003	-0.002	0.001
Temperament Inhibitory Control (teacher-rated)	3.7	2.3	0.69	0.46	0.46	0.29
Age (years)	19.31**	6.8	2.9	1.95	1.95~	1.11
Female	2.74	4.92	3.26*	1.42	0.08	0.61
Constant	19.13*	8.76	-0.5	2.46	0.06	1.36

Note: ~ $p < 0.1$, * $p < .05$, ** $p < .01$; HTKS = Head, Toes, Knees, Shoulders; DCCS = Dimensional Change Card Sort; BDS = Backward Digit Span; MVPA = Moderate to vigorous physical activity

Table 13. Models Estimating Association between Percentage of Time in MVPA and Classroom-Based Self-Regulation following Outdoor Play

PANEL A: Imputed Datasets (*n* = 58)				
	Attention		Inhibitory Control	
	Est.	S.E.	Est.	S.E.
% of Outdoor Time in MVPA				
Linear	0.011	0.01	0.011	0.007
Quadratic	-	-	-	-
Temperament Inhibitory Control (teacher-rated)	0.11~	0.07		
			0.24**	0.07
Age (years)	0.47*	0.22	0.19	0.21
Female	0.001	0.15	-0.03	0.13
Constant	3.70***	0.3	3.22***	0.37
PANEL B: No Imputed Datasets (n = 41)				
	Attention		Inhibitory Control	
	Est.	S.E.	Est.	S.E.
% of Outdoor Time in MVPA				
Linear	0.02	0.01	0.12~	0.01
Quadratic	-	-	-	-
Temperament Inhibitory Control (teacher-rated)	.19~	0.1		
			.27**	0.09
Age (years)	.63*	0.27	0.22	0.26
Female	-0.09	0.21	-0.05	0.19
Constant	3.18***	0.42	3.17***	0.44

Note: ~ $p < 0.1$, * $p < .05$, ** $p < .01$, *** $p < .001$

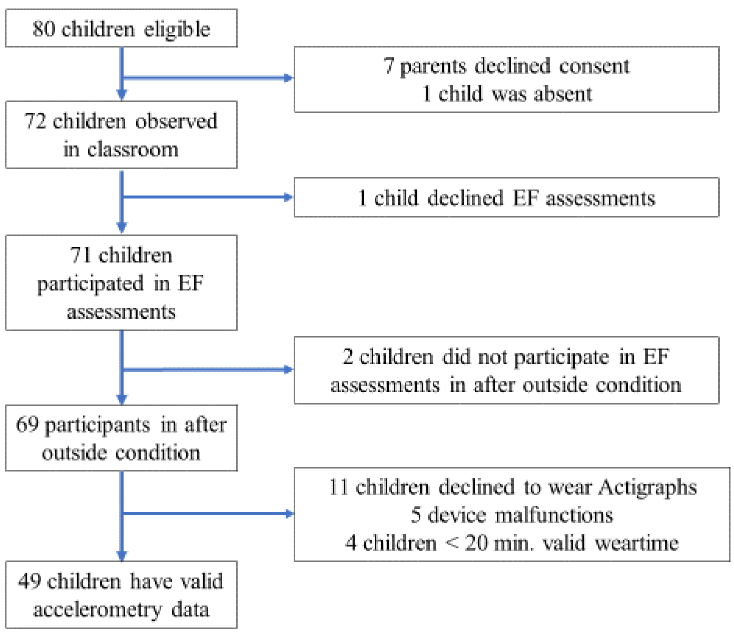
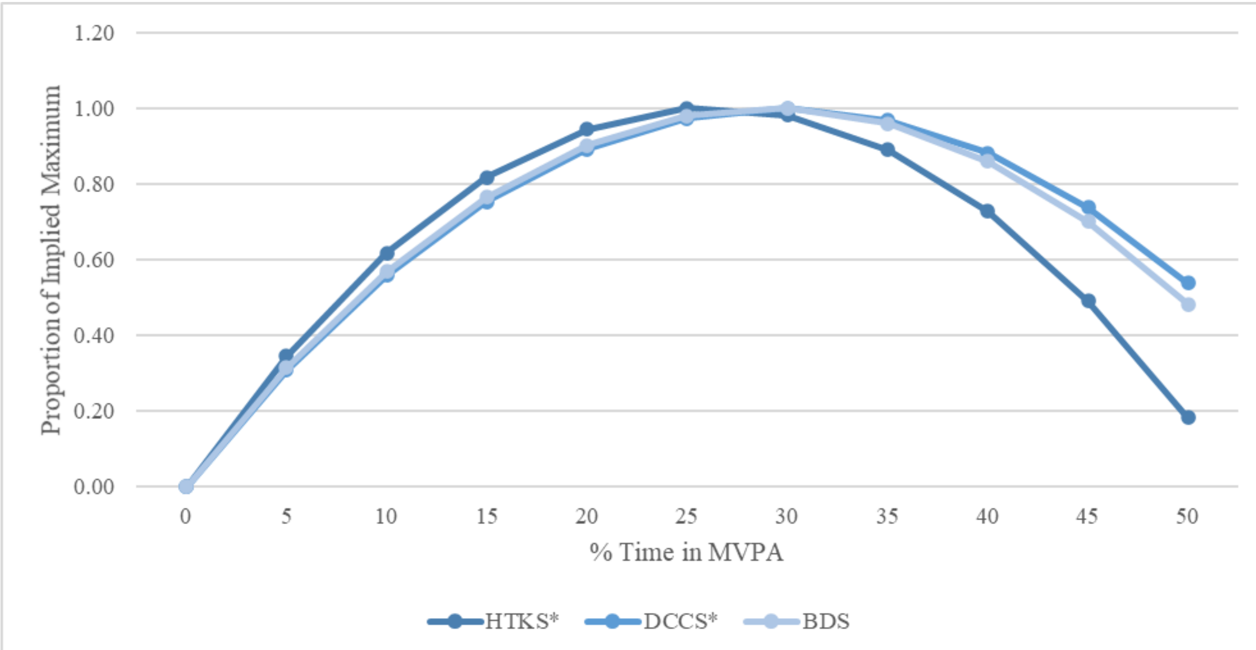
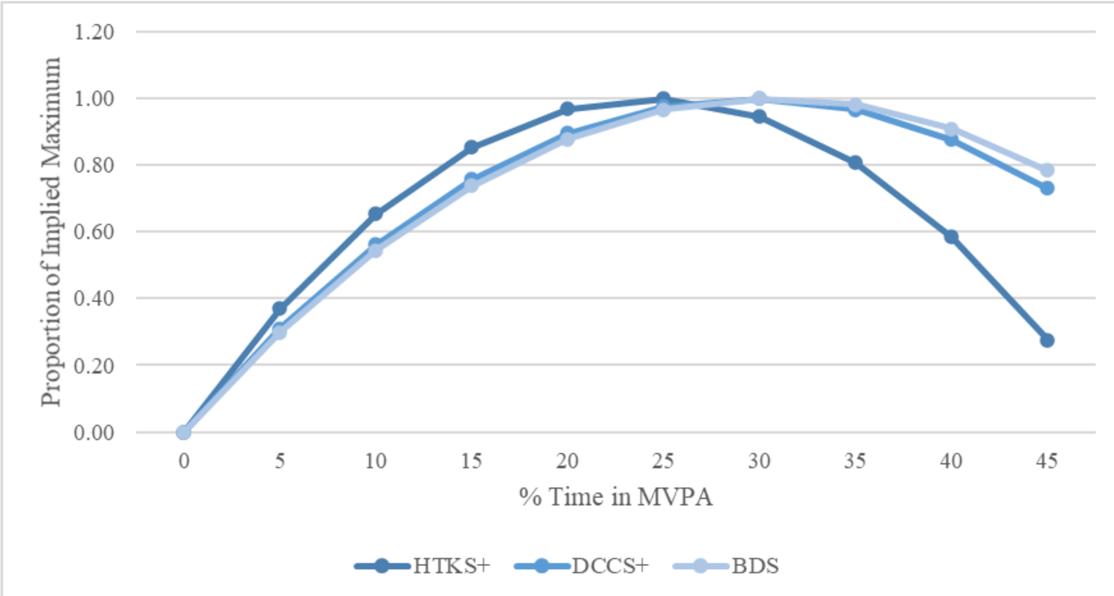


Figure 1. Flowchart Describing Sample Recruitment and Participation



Note: * *p* < .05 HTKS = Head, Toes, Knees, Shoulders; DCCS = Dimensional Change Card Sort; BDS = Backward Digit Span; MVPA = Moderate to vigorous physical activity

Figure 2. Quadratic functions implied by regression equations linking percentage of time in MVPA to children's task-based self-regulation following unstructured outdoor play with multiple imputation (n = 69)



Note: + $p < .1$ HTKS = Head, Toes, Knees, Shoulders; DCCS = Dimensional Change Card Sort; BDS = Backward Digit Span; MVPA = Moderate to vigorous physical activity

Figure 3. Quadratic functions implied by regression equations linking percentage of time in MVPA to children's task-based self-regulation following unstructured outdoor play without multiple imputation (n = 49)

Appendix

Daily Classroom Schedules and Study Activities

Table A1. Daily Classroom Schedule and Study Activities for Morning Preschool Classrooms across Study Conditions

Time	Study Condition 1	Study Activities	Study Condition 2	Study Activities
9:00-10:00	Center-based play indoors	9:30-10:00 one-on-one assessments of task-based self-regulation	Outdoor play	-
10:00-10:20	Snack	-	Snack	
10:20-10:40	Classroom circle time	Observations of classroom-based self-regulation	Classroom circle time	Observations of classroom-based self-regulation
10:40-11:45	Outdoor play		Center-based play indoors	10:45-11:15 one-on-one assessments of task-based self-regulation
11:45-12:00	Prepare for pickup	-	Prepare for pickup	

Table A2. Daily Classroom Schedule and Study Activities for Afternoon Preschool Classrooms across Study Conditions

Time	Study Condition 1	Study Activities	Study Condition 2	Study Activities
1:30-2:30	Center-based play indoors	2:00-2:30 one-on-one assessments of task-based self-regulation	Outdoor play	-
2:30-2:50	Snack	-	Snack	-
2:50-3:10	Classroom circle time	Observations of classroom-based self-regulation	Classroom circle time	Observations of classroom-based self-regulation

3:10-4:15	Outdoor play		Center-based play indoors	3:15-3:45 one-on-one assessments of task-based self-regulation
4:15-4:30	Prepare for pickup	-	Prepare for pickup	

Table A3. Daily Classroom Schedule and Study Activities for Full-Day Kindergarten Classroom and Study Conditions

Time	Regular Classroom Activities	Study Activities	Study Condition
9:00-9:30	Arrival and literacy		-
9:30-10:00	Classroom circle time and instruction	Observations of classroom-based self-regulation	Condition 1
10:00-11:15	Center-based play indoors	10-10:30 one-on-one assessments of task-based self-regulation	Condition 1
11:15-11:30	Story time	-	-
11:30-12:00	Lunch	-	-
12:00-1:00	Outdoor play	-	-
1:00-1:30	Indoor activities and instruction	1:00-1:30 one-on-one assessments of task-based self-regulation	Condition 2
1:30-1:45	Classroom circle time	Observations of classroom-based self-regulation	Condition 2

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